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The Scientific Method : Good or Bad?

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TO THE PEOPLE of his time, Galileo must have seemed a silly and a dangerous man. He would have appeared a silly poseur to the ignorant throng, and a dangerous radical to the scholar who had the insight to recognize the implied threat to accepted classical authority. Here was an iconoclast who had the audacity to use the bell tower of a cathedral to demonstrate that The Word might be wrong, in fact was most obviously wrong! Even students who have only a nodding acquaintance with the development of scientific thought know that the ecclesiastical authorities made Galileo take back his wrong-headed notions about the earth not being the center of the universe, but few of them are aware that he reneged on his "taking-back" and went further to describe his enemies unflatteringly in his "Dialogues on the System of the World" published in 1632.

For twentieth-century man to assume blithely that these differing points of view have been resolved forever in favor of Galileo is for him to miss at least part of the cause of the furor. Not all of Galileo's opponents were evil men. Many of them were earnest individuals trying to work out some order in a remarkably untidy situation; they were primarily concerned with the soul of man, and probably did not care a fig which celestial body revolved around which provided that man could come to know himself and to know God. Thus we have arising not merely a semantic confusion of words, but rather a discrete difference in the level of ideas. On the one hand, the zealous pursuer of facts that can be resolved into principles which can be demonstrated to be true, and on the other, the grim and unrelenting search to discover man's place in the universe, with the focus on man and a naïve acceptance of certain proclamations from the past.

The dedicated teacher would like to have an easy answer to the twin questions of what the scientific method is and to what extent

may it be used properly. He probably agrees with Cervantes' indictment of Don Quixote's maunderings among chivalric ramances:

> The poor fellow used to lie awake nights in an effort to disentangle the meaning and make sense out of passages . . . although Aristotle himself would not have been able to understand them, even if he had been resurrected for that sole purpose. . . . In short, our gentleman became so immersed in his reading that he spent whole nights from sundown to sunup and his days from dawn to dusk in poring over his books, until, finally, from so little sleeping and so much reading, his brain dried up and he went completely out of his mind.

Of course, the question of the meaning of scientific method is no farther away than that stated in Good's *Dictionary of Education* (1945):

> a plan or procedure in which a difficulty or situation is recognized, a survey made of available information relative to the problem, a hypothesis set up concerning possible solutions to the difficulty, the hypothesis tested experimentally under controlled conditions, the results collected, evaluated, and verified, their implications reviewed, and the hypothesis either accepted or rejected. (In the latter event, a new hypothesis may be formulated, and the entire operation repeated.)

Perhaps I was hasty in writing that the complete answer lies in the definition above for it seems to me that the chief ingredient of the scientific method has been left out. There should be a warning that subjective values must not taint the evaluating and that when we collect our findings, we must include all of the findings, not just those that please us. Also, in all fairness to the rapid reader and light thinker, it should be hinted that the whole definition simply systematizes the trial and error approach. You must record your mistakes, not bury them.

The apple that fell on Newton's head, the tinkering of Ford in a machine shop, and the doodles that Einstein twisted into equations produced an astonishing sequalae but gave us few answers to the problem of how man can know, and knowing, live in peace and harmony among his fellow men. In fact, there are some who suspect that the incredible increase in human knowledge, or rather, the vast accumulation of things now available for man to know, has made it harder for him to adjust, not easier. In somewhat less than four centuries we have reversed the telescope and fitted a microscope to its smaller end. We encompass more and see more deeply at the same time. Despite all of this, I have found few Miniver Cheeveys among us. The prevailing spirit seems to be that of determination to make these material objects subject to our will and to our direction.

How can we be sure that cornucopia pours out honey bees bearing nectar and not hornets laden with poison? Perhaps the best solution will be for us to learn and to practice rational thinking, which in itself presupposes an affinity for objectivity and an inclination to tolerance, here used in the sense of making room for the other fellow. Perspective is required. The mining engineer uses to good advantage the geologist's dry but accurate report of the topography of South Africa, but this circumstance does not prevent the same engineer's appreciation of the opening page of Paton's *Cry, the Beloved Country* in which the same territory is described somewhat differently:

> There is a lovely road that runs from Ixopo into the hills. These hills are grass-covered and rolling, and they are lovely beyond any singing of it. . . . The grass is rich and matted, you cannot see the soil. It holds the rain and the mist, and they seep into the ground, feeding the streams in every kloof. It is well-tended, and not too many cattle feed upon it; not too many fires burn it, laying bare the soil. Stand unshod upon it, for the ground is holy, being even as it came from the Creator. Keep it, guard it, care for it, for it keeps men, guards men, cares for men. Destroy it and man is destroyed.

The best current example of the union of the poetic and the scientific can be found in Rachel Carson's *The Sea Around Us.* *Life* Magazine has published, from time to time, beautifully illustrated stories of the earth and sea and of the development of life in both. Many of the new textbooks, and this is especially true of elementary texts and of literature series, have been colorfully decorated. Anything which arouses the interest and fires the imagination has an important humanizing influence on the subject-matter content. This blend of the factual and the artistic is helpful in encouraging rapport in the learner between what he knows and the meaning of what he knows. The knowledge of facts must be accompanied by an understanding of these facts in their several relationships before they can have genuine significance in the life of the student.

An example of this need for understanding which goes beyond the mere grasp of mechanical detail can be found in the automobile. Any good mechanic can explain the principle upon which the automobile operates; he can explore and repair with skill rumblings in transmission and differential. But to understand the meaning of the automobile to us and to the world is another matter entirely. The changes which this machine has wrought in the lives and customs of at least this nation can be counted and tabulated but

have implications far beyond statistical tables. For one thing, it has changed the patterns of courtship of our youth; for another, it represents sudden death.

More and more it has become evident that the physical scientists themselves recognize the need for a union of the sciences and the humanities. Dean W. L. Ayres of the School of Science of Purdue University writes:

> In the case of young physicists and chemists, I should also suggest the possibility that there appears to be an absence of social science and philosophy in their training. It has been my observation that the students majoring in the fields of physics and chemistry resist most violently any attempt to broaden their education into the field of social science and philosophy. Someone has remarked that one of the most peculiar phenomena of the post-World-War-II years was the frantic search of the nuclear physicist for a social philosophy.[1]

Even more strongly the point is made by Dr. Henry Margenau, Higgins Professor of Physics and Natural Philosophy, Yale University, that:

> There should be much closer liaison between the educator and the scientist. The former must remember that no amount of pedagogical skill can offset lack of training in the sciences, and the latter must acknowledge that familiarity with subject matter does not in itself make a good teacher. I should like to see the day when the distinction between the educator and the scientist fades away, both administratively and in the attitude of these professions; when students who prepare themselves for a teaching career will be taught science by men actively engaged in research; and when a Ph.D. in physics or chemistry will be required to take courses in pedagogy, psychology, and perhaps public speaking before he can be a candidate for teaching positions in our colleges.[2]

The products of the age of science are upon us; we cannot avoid them, even if we were so inclined. Neither can the procedure by which these achievements are realized be ignored. Near Soldiers Field in Chicago, on a cold day in the fateful fall of 1942, a group of scientists watched anxiously as the first atomic reactor started. Some of them have confessed since that they hoped that the experiment would be a failure. They did not wish to contend with what they had created; they did not want the responsibility for the use to which it might be put. In themselves these creations of the scientific method are neutral, they are neither good nor bad. As we grapple with the objects in our environment we must strive equally hard to determine and to plan the design which will permit us to use these material things constructively.

[1] Association for Higher Education, *Current Issues in Higher Education 1953*, Proceedings of the Eighth Annual National Conference on Higher Education, Chicago, Illinois, March 5-7, 1953. Pp. 172-173.

[2] American Association of Colleges for Teacher Education, *Sixth Yearbook*, 1953, p. 138.

Research in the Physical Sciences*

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RESEARCH is the essence of modern science. The general research approach to physical environment has developed over the past three hundred years, and is still changing. This way of inquiring about the world has been so successful and effective that some have given "science" an aura and prestige of terrifying magnitude. In view of this, my comments will deal with some of the limitations of scientific research, with some of the things which science is not. Immediately we should note that the methods of modern science provide only certain kinds of information about certain kinds of things and events. No valid claim can be made that through science one learns "all about" anything or that the methods of experimental science are applicable to all areas of human interest. Certainly aesthetic and religious questions are not subject to the methods of inquiry employed in science.

When the place of science in the culture is discussed there is sometimes a feeling that science as we know it is apart from or in conflict with basic tenets held desirable by the society as a whole. This is unfortunate.

Barber, in his recent book *Science and the Social Order*,[1] identifies five major joints on which scientific inquiry and the tenets of western culture are congruent. These are: rationality, utilitarianism, universalism, individualism, and progress and meliorism. By rationality is meant the assumption that the phenomena of the world can be reduced to order through reason. Basic to this is free inquiry on all topics of interest. Not only in science but also in industry, in politics, and in government we find this "critical approach to all phenomena of human existence."

Utilitarianism is a term employed to mean primary concern with affairs of this world rather than "other worldliness," a concern prevalent in western Europe during the Middle Ages and in some of the cultures of the Far East. To some extent concern with the affairs of this world may appear as a feeling that men are "God's stewards" to take care of the earth; it may, but need not, become "materialistic." Universalism seems, to Barber, to represent the

* Reprinted with permission from *Phi Delta Kappan*, October, 1953.
[1] Bernard Barber, *Science and the Social Order*. Free Press, 1952.

freedom of each individual to seek and to choose his own life's work. If successful, the individual is then treated and judged by applicable science norms. It is directly counter to privilege by birth, race or color.

Individualism places responsibility for a person's life upon himself, and removes it from the dictates of some other organized authority. Such an attitude is especially conducive to development in the creative arts, whether painting, music, literature, or the sciences, and it is contrary to "planning" or forced direction of activity. Finally, progress and meliorism is based upon the belief that active rationality should improve man's lot in the world, and that the results of such rationality will be cumulative.

Barber observes that in no society are these characteristics found in perfection, and that each, to some degree, may be in conflict with other ways of looking at the world. He further shrewdly observes that some form of science will exist even though several or possibly all of these characteristics are abandoned by the society. However, the type of scientific activity which has developed in western societies during the past three centuries appears to be consistent with and to flourish when these precepts are widely held.

Despite easy statements to the contrary, science as we know it is still part and parcel of the total culture. The basic, unstated philosophical milieu within which a scientist is reared and in which he operates is the culture of the time; it permeates what he will do and how. Only to a minor degree, and slowly, do the results of scientific investigations and their possible technological applications affect the speed or the degree in which various of these precepts are accepted and emphasized in the society. One would be very rash to assert that the scientist was apart from society or that his work dominated the concept of the "good life."

Specifically, we do not have a technological society because scientists have been successful and engineers skillful, but rather because we have desired the fruits of technology as this form of enterprise flourished. The distinction may be made clear by recalling that the Chinese knew of the magnet and of gunpowder long before they were known in western Europe. Because their center of concern differed from ours, we may note, perhaps with some envy, that the Chinese used gunpowder for gentler purpose than did our ancestors. Or in a more recent example, we do not have atomic bombs because scientists were inherently destructive, but rather because the nations of the world drifted into a war which, in turn, motivated

the government to buy two billion dollars' worth of effort to see whether the laboratory discovery of nuclear fission could be developed into a dreadful weapon.

As the successful application of experimental inquiry has expanded and matured, thoughtful people have examined into those extravagant claims made by some scientists over the decades. Rapidly disappearing is the assertion that through scientific exploration man has contacted "reality." The current and more modest view is that the scientist describes selected aspects of what occurs in the world, either commonly or under special experimental circumstances, and then attempts to "make sense" out of this additional information. The kind of sense accepted by the scientist must meet certain criteria which are important to science per se. Of first importance is the criterion of fruitfulness—that is, the ideas developed as explanations and inquiry. Otherwise the ideas may be neat but sterile. In addition, the ideas should be as economic as possible, in the sense that the number of assumptions should be at a minimum and the generalizations terse and explicit.

These components of modern science are important for they lead to the continuation of such inquiry under its own internal set of checks and balances. Ideas and information advance together and neither can far outstrip the other.

This picture of science, as seen by the scientist, differs greatly from that commonly held by non-scientists. All too often science is vaguely visualized as the progenitor of bigger, shinier, more expensive, and sometimes more dreadful gadgets and devices. The production of these devices falls in the area of technology, which is markedly different from science and is heavily motivated by social necessity and monetary profit. In fact, it may be helpful for us to examine science as consisting of at least four separate components. S_1 is science to the individual scientist. All too often we overlook the fact that creativity resides in the minds of men and that an idea first occurs to some one individual before he can communicate it to any others. In science, as in any of the other creative areas of human endeavor, the individual is paramount. James B. Conant has observed that one first class scientist is worth more than ten of lesser ability. The way in which the individual creative scientist looks at the world and at his own life strongly influences the phenomena he will consider and what aspects he will abstract for theorizing.

S_s represents the community of scientists. Through their professional meetings and journals they scrutinize and criticize the proposals made by themselves as individuals. Such open scrutiny and appraisal of results guarantees a stability and continuity to the scientific inquiry far greater than could be provided by any outside agency. Within this society of scientists each individual decides for himself, and may change his mind if he is so inclined, regarding the usefulness of any particular proposal. A time delay in the acceptance of new ideas is then inevitable. Any radical idea is by definition likely to attain little initial support, but the long-term test of utility operates to separate the wheat from the chaff. This is illustrated by a story about the famous Swedish chemist Arrhenius whose doctoral dissertation contained novel ideas about chemical ionic reactions. The board of reviewers were not able to appraise the possible long-term value of the ideas. They decided that if the ideas were incorrect they should not have been presented as the basis for a degree, but that if the ideas were correct Arrhenius would not need the degree. (P.S. He did not need the degree.)

S_t is the area of technology and engineering where the ideas and information of the society of scientists are translated into things and operations for social use. Numerous selection screens operate here to determine what will be developed, by whom, how, and when. On one side we may have the idea of the "social good" whereupon the government, local, state or national, may take the responsibility for certain developmental work. This might involve the construction of a dam for flood control and generation of hydro-electric power. Or it may involve the development of new weapons asserted to be necessary for the security of that society. On the other hand it may be a development carried on by private enterprise where the primary criterion is the monetary reward to be expected.

S_p is science as seen by the general public and for the most part this consists of a distorted image of S_t, modern technology. In this day of electrical gadgetry, radio, and television it is perhaps a surprise to learn that the identifiable beginnings of these modern devices lie back in the 1830's with the work of Michael Faraday. His simple equipment and experiments, guided by a most penetrating insight and wisdom, appeared to be "utterly impractical." At one time a venerable dowager is said to have asked him, "Mr. Faraday, what is the good of all this?" To which Faraday replied, "But madam, what good is a new born baby?"

More than two decades later James Clerke Maxwell extended the studies of Faraday and of others in a beautiful set of mathematical equations—here again "obviously impractical." After another two decades, in the 1880's Hertz began "impractical" experimentation to see if certain conclusions derived from Maxwell's equations might have any counterparts in experimental science. Thus wireless and modern radio and all the other communication devices were conceived, but they appeared slowly over decades. Every field of modern science has likewise had a long period of gestation, and of babyhood.

If any peculiarities exist between science and other types of creative human endeavor, these differences reside in the types of data and phenomena available for study. Certainly the differences between the various sciences are themselves a reflection of the differences in the information on which thoughtful people can ponder. Geology is inherently different from physics, not because one is "better" than the other but because the types of information available to the investigator differ. In fact, a course in "comparative science" like comparative religion or comparative education might be profitable to both future scientist and future layman.

Such a view of modern science has strong educational implications. First, science is one of the creative arts. Out of the disciplined imagination of men come ideas which tersely organize diverse phenomena of the world in economical generalizations. Only through informed and imaginative individuals does this occur. Obviously, our schools should then help to identify and to encourage all such creative individuals.

Also, we should show those who prefer some other field of work the actual nature of scientific inquiry. Far too often, however, we find science classes consisting of the bare bones of science—encyclopedic information—with all the functional viscera and guiding mentality eliminated. Little wonder then that many adults have come to look on science as frightfully dull and upon scientists as strange people.

If any useful lesson can be transferred to research in education, it would be that each of the sciences has of necessity developed both its own methods of inquiry relevant to the available data and its own set of postulates. In education we would do well to stop mimicking the physical scientists.

A final aspect may also be worthy of transfer to education and the other social domains. In science, thousands of individuals are

patiently attempting to add to available knowledge and theories. For the most part these inch along, growing by small increments, and within the total field of science any particular result is a very modest edition. Unfortunately, in education it seems that each small increment of knowledge is exaggerated out of size and context to appear as the panacea to all our intellectual and social ills. New fads in education appear overnight like frost, but soon melt away to small, useful residues. Let us be more modest about our results and ideas and more productive of them.

How Shall We Teach Science?

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A GREAT DEAL has been said and written during recent years concerning the theory and practice of science education. Assuming that persons presently certificated as teachers in the public secondary schools of the nation are thoroughly competent in terms of background, training, and personality to do a good job, there remain the twin problems of attitude and orientation. Why is it that some high schools seem to function collectively and in evident harmony with regard to life preparation in general and science education in particular? Why is it that some people work equally well with young people and other members of the faculty? Wherein lies the spark which gives a few leaders that extra measure of power and achievement which is so characteristic of winners in this as in every other field? What makes a good science teacher good? Does he do it all by himself? Who helps him? In what ways? How does he help others? How shall the science teacher teach, in terms of general education?

Science is exact. Content material must be accurate, if the science teacher is to teach the truth. Limitations as to coverage, attention span, mental "set," individual maturation, socially competitive activities, and comparative subject difficulty offer no real handicaps to effective science presentation. We may not teach *much* in the tenth grade, but what detail we do teach must be *right*. Professional associates from the superintendent to the assistant janitor respect the teacher in any field who never compromises with

fact. Each student will learn to realize that generalities, haphazard guesses, and wishful thinking have their places in life from a rationalization viewpoint, but that these intellectual luxuries are recreational and diversional to the scientist. Respect for truth upon the part of the teacher breeds respect for truth upon the part of those students who spend part of every school day in his laboratory.

Science is ethical. In our teaching we shall strive to imbue each pupil with an idealistic zeal for altruistic good. We shall not permit subversion, disloyalty, or malpractice in our classrooms, for no scientist or research worker countenances cheating or misrepresentation in any form. Plagiarism and charlatanism are condemned in all fields of human endeavor, but in science such behavior is anathema. The idealism of the science teacher cannot but contribute to the character development of his charges. The Golden Rule is applicable here as elsewhere in life.

Science is essentially experimental. We shall teach the virtues of pragmatic observation through manual dexterity as well as mental participation. We shall contribute to pupil self-confidence in and out of school as we foster development of ability through performance in the laboratory and in the field. Our young people must learn to say: "I wonder!" "Let's go and look!" "How about our going over there and finding out?" "What do you say? Let's try it and see what happens!" The experimental method implies far more than copy-book busy-work in the science classroom today. It may lead far afield. The amplified, expanded concept is vital to the successful culmination of our effort. The method itself is tried and true; it works through motivation, sustained interest, and desirable end-products. Let us not set it aside for the techniques of the demonstration table and wall chart. Each of the latter has demonstrable place in good science teaching, but not at the expense of personalized experience. Textbook science, like textbook farming or chicken raising, is theoretically permissible but practically inefficient. Let our embryonic chemists learn to manipulate the tools of their calling; let our youthful biologists feel animal tissue; let our future agronomists actually feel the soil; let our incipient botanists consider the lilies in the field. This is the essence of the experimental method.

Science is social. We shall teach science in terms of human relationships. Beyond this, we shall teach science in terms of conservation of natural resources, preserving all that is good and contributing to the elimination of all that is bad in nature. This

thread shall run through every experiment, assignment, research problem, and group discussion. The osmosis of science and society is fundamental in terms of adult American citizenship, and constant allusion to the factor of social awareness in the science classroom will constitute a genuine step toward consummation of an ideal in secondary school education. To so prepare our young people that an equilibrium of social action and reaction may be attained upon a basis of science-school-community orientation, interchange, and mutual cooperation is indeed basic to general education. We shall teach science to build for sound citizenship as well as for individual competence contributing toward survival in the continual struggle for success in life. We shall teach science through cooperative effort of instructor, reference books, research teams, individual and group discussions, parental participation, and civic-industrial interrelationships. The interdependence of science and society is no idle phase in such a classroom laboratory, for here is the crucible of American citizenship.

Science is reverent. There are many agnostics but few atheists in the world of science, for no man may study long before he sees revelation of divine power in infinite nature. The biologist thrills at the unfolding flower, the developing embryo, the functioning cell, the latent gene. The physical scientist produces new substances from familiar ones, builds for the future as he aids life in the present, looks deep into the earth and far out through the universe of suns. We shall teach reverence as scientists understand the word: hopeful, confident, submissive, self-effacing, but determined in dogged tenacity, as a minister of the Gospel is determined. The pure scientist and applied scientist alike strive to reveal, through personal effort and divine grace, new knowledge for the betterment of mankind and all that is good in nature. Men and women of science the world over endeavor to stamp out disease, to foster the worthwhile, and to stamp out that which is not good. We shall teach science with reverence, for these things are in His name.

How may secondary school teachers transfer such idealism into realistic achievement? Assuming technical competence, individual initiative, and a motivating spirit of professional cooperation, how may the science teacher become more effective as a modern educator? If it is true that child development is the result of many life experiences (in school and out) how may we bring about desirable social objectives while teaching science? An overview of the secondary school curriculum may provide clues with relation to general education.

The typical profile is of course the separate subject matter, vertical administrative plan wherein general science, biology, botany, zoology, physiology, earth science, chemistry, and physics are considered as separate entities, entirely independent of other subjects and the people who teach them. Science thus competes with art, social science, shop, gym, and even with other science courses for a place in the adolescent sun. This in itself is not bad; it is good. But it is not good enough! By itself, no science will accomplish the aims and objectives we have described. By himself, no teacher can hope to make his own subject omnipotent in terms of education of the whole child.

A few urban systems have adopted the "broad fields" coverage in laudable attempts to socialize science. In such teaching, science is considered as an interlocking subject, covered through specially designed survey-type orientation courses. "General Science" began this trend many years ago, the success of the course being relatively dependent upon the individual social consciousness of the instructor in charge. In some places it worked admirably, and still does. In others it has shown itself to be a miserable failure. More recent survey-type courses include "Life Science," "Earth Science," and terminal "Senior Science," most of them having had considerable success in many modern high schools.

The third organizational plan is known as the "integrative core" curriculum. According to this concept, ALL subjects are brought together by ALL teachers in the school. Each subject specialist metamorphoses as educator, each bringing contributory factors to bear upon the learning process with relation to his or her special field. This is admittedly "progressive," but it has had remarkable success in many instances. Social science—science correlation and integration are most efficiently interrelated in this way, once the intitial departmental barriers have been broken down. Experienced educators in both fields are understandably dubious concerning results to be expected through such coordination, each feeling that the other group is more or less poorly equipped to handle subject matter in related fields.

The obvious remedy is the faculty seminar. If members of the staff agree to come together for presentation, discussion, and interplay of ideas, the integrative core may have considerable merit. Of course history teachers will not be expected to set up photosynthesis demonstrations or to dissect lower mammalian cadavers, but they may make undeniable contribution to adolescent mastery and per-

spective through parallel discourse upon the life and work of Senebier, De Saussure, Galen, and Harvey. High school instructors in chemistry quite usually invoke the accomplishments of such men as Joseph Black, Joseph Priestley, and Antoine La Voisier. Physics teachers dramatically portray the accomplishments of Galileo Galilei, Isaac Newton, and the Curies, as historical and socially significant background for their own presentations. Perhaps if more teachers of sixteenth-century history had been consulted by more science people, Galilei would not have been known by his given name for so many centuries, a popular and professional error! A science teacher's presentation is no better or more factual than his information!

The "how" of science teaching is thus basically dependent upon the curricular organization, the course of study employed, and the administrative insight of principals, supervisors, and superintendents involved. Beyond these, however, lie the morale and *esprit d' corps* of the class room teacher. Contrary to popular opinion, science instructors are *not* all limited in social living, either personally or professionally. Many science people are *not* excessively introversive and dogmatic. The science teacher is exact in his passion for accuracy. He is the most ethical of workers. He is by nature and training an experimentalist and pragmatist. He is, if successful, reverent toward the Creator as toward his fellow human beings, including his colleagues as well as the young people enrolled in his classes. It is probably true that no educator is at heart more aware of the relationship of his technical field to society, for no subject in the secondary curriculum is more social in life impact than any one of the sciences.

Each teacher teaches according to his own convictions as to what methods are best for the grade level concerned. A few still abruptly reject the "interest-centered class room" as utterly impractical in the secondary classroom. Some enthusiastically embrace the broad coverage concept. Our leaders in this field will resolve to do what they can to break down departmental barriers, professional jealousies, and personal prejudices which inhibit accomplishment of the ideal. Where democratic interplay is permitted and interchange of ideas and content information is fostered, our best people teach science in the midst of a glowing, vibrant, pulsing atmosphere of social awareness. Such orientation is truly effective as an agency of general education in the "whole child" sense: education for life.

What Mathematics Is Essential?

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NEARLY EVERYONE agrees that mathematics is an essential part of a general education at the secondary level. This happy state of unanimity disappears when an effort is made to give specific answers to questions about content and method. Diversity of opinion is then the rule. Differences exist not only between the views of the mathematicians and those of the "general educators," but even among the mathematical experts themselves. The problem of determining what mathematics is essential has no neat mathematical solution.

Three general varieties of opinion will be recognized here. Some persons, in planning the curriculum, would provide mathematics at a subsistence level only. They would expect students to learn only enough to eke out a precarious existence on a stern and rock-bound mathematical coast. A second variety of opinion would provide a curriculum adequate for comfortable living in a pervasively mathematical culture. A third view is held by those who would provide for some mathematical luxuries. General education, viewed as liberal education—befitting a freeman, a gentleman, or a non-professional person—then includes mathematical concepts for utilitarian purposes supplemented by more or less generous doses of appreciational vitamins.

Many discussions of the question of essentials tend to emphasize mathematical content. An effort is made to secure a definitive minimal list of concepts, topics, and operations which are to be prescribed for all students. A different approach to the problem puts the emphasis on mathematical behavior, stressing characteristic *ways of thinking* that are used by mathematically competent persons. The most effective efforts to specify an essential mathematical training are those that give attention both to the behaviors sought and to the content with which they operate.

The remainder of this discussion will sketch some mathematical content and behaviors believed to be essential at the subsistence level, at the level of "comfortable living," and at the idealistic level of luxurious intellectual living.

The Subsistence Level. At this level, the content is largely arithmetic. The ability to compute with the integers (the whole numbers) is indispensable. It is of course true that most of the computing in stores, offices, and factories is now done with the help of machines. However, these machines are as yet neither common household equipment nor readily portable in a hand-bag or tool chest. Much figuring is still done on paper or "in the head."

Some understanding of common and decimal fractions is also minimal, but it is doubtful that the subsistence level demands the ability to do more than the simplest of calculations with common fractions. The basis for this last statement is the well-known fact that millions of citizens now exist comfortably without knowing how to compute with fractions. Many students are graduated from high school and admitted to college without this ability. Decimal fractions in the special context of "money" are, however, so important that they may be called essential elements of a general education. It is also true that an understanding of percentage, and the ability to use it in connection with discounts and many other applications, is not to be neglected.

If citizens are to be able to interpret data essential for an understanding of many important problems—economic, political, health, and others—they must be able to interpret such data encountered in the form of tables and graphs. Finally, they need to know a few elementary geometric concepts, including the meaning of such terms as parallel, perpendicular, angle, right angle, square, and like. They must also be able to measure lengths, compute the area of simple figures, and read scale drawings and maps.

Other items could, of course, be added to the list, but in any event the subsistence level of mathematical competence only calls for learning that should be achieved by the end of grade IX, or preferably, sooner. Unfortunately, even this is not universally accomplished at the present time.

The emphasis thus far has been on content, but behavior has also been suggested by the verbs *compute, understand,* and *interpret.* The basic behavior is suggested by the term *problem-solving.* Even at the subsistence level, behavior of this type occurs. The objective of the mathematics program is to help students learn to recognize and clarify their problems, to attack them with quantitative concepts and methods when these are appropriate, and to arrive at decisions, conclusions, or judgments supported by accurate computations and sound interpretations of the data.

In the past many teachers of mathematics have emphasized the computational aspects of mathematics more than problem-solving. Students who are working toward a subsistence level only are as a rule of low ability and poorly motivated. Problem-solving is difficult for them. Nevertheless, computational ability is only a means to an end, and neglect of problem-solving because it is difficult is not a valid procedure. Instead, attention must be given to the selection of problem situations at an appropriate level of difficulty, followed by careful developmental teaching of the necessary behaviors. Existence without problem-solving ability would be below the subsistence level, or is possible only in an Utopian culture where no problems are encountered.

Mathematics for Comfortable Living. Not many teachers of mathematics are prepared to accept the attainment of only the subsistence level as their goal for students. When one turns from consideration of the mathematics essential for subsistence to that needed for "comfortable" living, the objectives are much less clear. A frequently cited formulation is the Check List of 29 questions given in the *Guidance Pamphlet in Mathematics.* This pamphlet constituted the Final Report of the Commission on Post-War Plans of the National Council of Teachers of Mathematics. Of the 29 items, perhaps 16, or a little more than half, might be considered as applicable at the subsistence level. The others seem clearly to be above that level. Among these are the items indicated briefly by the following terms: (15) Constructions; (17) Vectors; (20) Algebraic symbolism; (21) Formulas; (22) Signed numbers; (23) Using the axioms; (25) Similar triangles and proportion; and (26) Trigonometry.

The concepts and abilities suggested in connection with these items are rather generally believed to be sufficiently pervasive in modern life to warrant the claim that an educated person should have them. A strong argument can be given that one needs at least this much mathematics to read intelligently from newspapers, magazines, and books of the non-fictional type in order to be informed and gain understanding of the world. These concepts and abilities are also needed in the study of other subjects, notably the sciences and to some extent the social sciences.

At the present time the topics in the above list are commonly taught in a course called *General Mathematics* or in *Algebra.* Often the orientation is toward vocational use or college preparation. When viewed as components of mathematics essential for comforta-

ble living, neither of the above purposes is necessarily implied. Rather, the argument should be that to live effectively in the modern world, the student will need at least this much regardless of his destination. If this viewpoint is taken, the behavior sought, and particularly the kind of thinking desired, leans noticeably in the direction of understandings and interpretative abilities, rather than toward skill in operational technique. Some of the latter is doubtless necessary to secure the understandings and interpretations. The level of computational performance, however, can legitimately remain below that expected of a student who expects to use this mathematics vocationally or who is preparing for a profession.

Mathematics Essential for Understanding Mathematics. It was pointed out earlier that there are some who define general education in a way that tends to identify it with the liberal arts tradition. Such persons place the threshold for the term "essential" far above the subsistence and utilitarian level. Mathematics is, according to this view, a subject to be studied for its own sake—or rather, for the sake of the intellectual satisfaction derived from the study. It is analogous to an art.

When this point of view is dominant, it is likely to carry with it the notion that a student can only understand mathematics in terms of certain modern viewpoints. In particular, considerable emphasis is placed upon logical concepts and principles. The role of undefined elements, of definitions, and of axioms or postulates, must be clarified. The basic postulates of particular mathematical systems (e.g., the integers, the rational numbers, Euclidean geometry) must be identified. Concepts like *set* (class, aggregate), and of membership in a set, may be introduced and extensively employed. More attention than usual is given to the historical development of the subject, to famous problems solved and unsolved, and similar topics.

The mathematics courses in the traditional high school curriculum—algebra, geometry plane and solid, trigonometry—really serve a dual purpose. For many students they are vocational and a part of special education. When students are preparing for careers in science and engineering this vocational aim is clearly understood. It is less obvious when the students are not yet clear as to their goals. At the same time these courses have, if they are being adequately taught, a strong flavor of the liberal arts approach. The preprofessional students usually have sufficient intellectual interests to enable them to gain satisfaction from their study over and above

that which comes from anticipation of its applications. Other students, usually in the same classes, may be taking the work not because it is required of them, but because they succeed well with it and they enjoy it.

Only a part of the total secondary school population seems to be capable to deriving much aesthetic satisfaction from mathematical study. Similarly, only a part of the student group ordinarily derives satisfaction from classical music, from poetry, or from examples in the visual arts. When general education is so defined that it is limited to objectives that all students are to achieve, most of the mathematics in the traditional program must be excluded. If, however, a broader definition along the lines of the liberal arts tradition is adopted, then it can be argued that it is essential that provision be made in the program for an approach to mathematics which is not purely utilitarian in a narrow sense of this term.

Although there is no one answer to the question as to what mathematics is essential, the situation today is far from discouraging. Attention is now being given, as it seldom was in earlier times, to the issues involved in approaching such a question. What values do we want to achieve? Are we to educate all, or only a few, at the secondary level? The answers to these underlying questions have begun to settle out in recent years, and we can go on from there. Some may be satisfied to achieve only the subsistence level of mathematical competence. Most persons will strive for at least enough mathematics for comfortable living. A relatively small group, but still appreciable in total number, will think that to dig deeply into mathematics is essential to their happiness.

Potential Contributions of Mathematics to a General Education

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IT IS TAKEN for granted that everyone should study one's native language sufficiently to use it correctly and effectively in spoken and written communication. Some knowledge of the history of the race, particularly the history of western civilization, is generally accepted as essential in the education of all citizens. What of mathematics? What are its claims to inclusion in general education? What unique contributions does it have to offer?

Perhaps more than most subjects, mathematics means vastly different things to different people. To some it is calculation, reckoning pure and simple. To others it is a powerful tool, indispensable to the engineer, the scientist, and other specialists, but of no great concern to the average man. Mathematics has been called a language with its own peculiar symbolism and rules of syntax. Many mathematicians think of their subject as a logical structure, built upon undefined terms and axioms, and developed by deductive reasoning. There are even people who regard mathematics as a sort of occult science capable of throwing "light on all dark things."

It is indeed true that mathematics has many facets. Mathematicians do not agree among themselves upon an acceptable definition of their subject, nor are they all interested in the same aspects. Some delve into its foundations, others spend their lives developing some particular branch, some are interested primarily in applications. Because of the multilateral character of mathematics, many diverse reasons have been given for its inclusion as part of a general education, the emphasis usually reflecting the interest of the writer.

The practical utility of certain topics in high school mathematics is obvious. Among these topics may be mentioned: ordinary computations of arithmetic; formulas, graphs, and solution of simple equations in algebra; mensuration formulas and properties of frequently encountered figures from geometry. These things anyone may reasonably expect to use in the course of everyday living. And it should be pointed out that the age of technology in which we live makes some knowledge of elementary mathematics a practical necessity for many people in holding down their jobs. Mathematics is being applied in more and more areas of human activity. For specialists in a great variety of positions in industry, business, and government, a knowledge of a considerable amount of mathematics is absolutely essential. There are more opportunities for young people with substantial training in mathematics than in any previous generation. These facts must be taken into account when planning a general education program.

But I want to discuss some other aspects of mathematics. A child has a right to expect more from a general education than just those things needed in making a living, more than those bits of knowledge useful in buying groceries, measuring a room for a carpet, or sending a telegram. An education limited to the immediately utilitarian is inadequate for training a citizen to take his

proper place in a democratic society. The proper operation of a democracy requires that its members function as rational beings, capable of making reasoned decisions, sensitive to opportunities and obligations, able to distinguish between good and evil, significance and triviality, truth and falsehood. The success of current commercials on the radio is a sad commentary on the cultural level of too many of our people. Education—better education—seems to be the only real hope of raising this cultural level. In the area of general education, besides the practical utility of its simpler branches, what does mathematics have to offer the average person?

The mathematics in existence today is an important part of our cultural heritage. The day is long past when anyone, even the greatest mathematician, can know all of it. But in understanding the development of our civilization, its science, its technology, its philosophical thought, one cannot ignore the decisive role which mathematics has played. The influence of Euclid's *Elements* on the course of human thought is incalculable. The invention of an effective symbolism in algebra, with the added power it gave to mathematicians, might be compared in some measure with the invention of the wheel. To contemplate a situation in which we would be deprived of the Hindu-Arabic system of numeration and forced to use some such system as that of the Romans is to get some notion of the implications which the introduction of our present system of numeration had for commerical life in subsequent times.

It is not easy to convey to students a proper appreciation of the power and significance of mathematics. It is surely not enough to remark from time to time that the subject is important and useful. Illustrations, really impressive examples and not trumped-up trivialities, given in the proper context with adequate explanation, can be helpful. Certainly, a clear and enthusiastic presentation of whatever branch of mathematics is being taught will impart to at least some students a recognition that here is a subject of importance, worth the work necessary to understand it. There is no substitute for the teacher's enthusiasm and belief in the importance of the subject. A philosophy of education which belittles the importance of subject matter leads inevitably to superficiality, with an absence of any real intellectual activity. A teacher without a genuine interest in his subject can no more give a good performance than can a musician who does not like music.

Reference was made earlier to logical reasoning. Does a study of mathematics cause one to reason logically? Not necessarily, but

it can help. Better than any other subject in high school, geometry presents a model of a logical system, in which assumptions are explicitly stated and their consequences derived by deductive reasoning. Of course, not all correct reasoning is deductive; inductive reasoning, whereby a general conclusion is reached after a study of many particular cases, is a necessary and valid form of thought. Much of the knowledge in the natural sciences is obtained by induction. But the form in which many everyday discussions are cast, particularly those of a controversial nature, is that of deduction. Usually, the premises are left hazy, sometimes deliberately so. If you grant a man enough assumptions, he can prove anything and do it without violating any of the laws of logic. But many people are also taken in by faulty logic. The following is a familiar example of fallacious reasoning practiced by political demagogues, unscrupulous salesmen, and the like. Suppose p and q represent propositions, which may be true or false. Suppose it is shown that:

1. If p is true, then q is true.
2. q is true.

An unwary person might be induced to conclude from these two facts that "p is true" follows. For example, it might be argued: "If this man were guilty, he would run when accosted. He ran when accosted. Therefore, he is guilty." A simple example from arithmetic demonstrates the faulty deduction. Let us establish the proposition: "If $1=3$, then $4=4$."

Proof. $1=3$ (By hypothesis.)
$3=1$ (Interchanging sides of the equation.)
$\overline{4=4}$ (Equals added to equals give equal results.)

Thus the proposition is proved. The conclusion of the proposition is certainly true. But everyone would agree that the hypothesis is false.

The mathematical example given in the preceding paragraph was used for the purpose of demonstrating a fallacy, and it is important to recognize fallacious reasoning. But, to look at a more important contribution, a branch of mathematics, such as plane geometry, developed from a set of axioms exemplifies logical deduction in a particularly clearcut form. Students may be given much valuable practice in following logical arguments and also in constructing them. Of course, this does not guarantee that students trained in mathematics will necessarily think straight in other areas. But contact with a discipline in which logic and not authority is the final arbiter of correctness, and in which sloppy thinking can

usually be demonstrated as such, furnishes students with criteria of logical rigor and a very real possibility of developing habits of orderly thinking which will stand them in good stead whatever careers they may follow.

One should also note the attention given to precision in mathematics, not only in computation but also in verbal statements. This feature can be used to impress upon a student the importance of saying precisely what he means, of using language with care and exactness. Frequently, in mathematics, a very slight carelessness in wording makes an otherwise true statement into one which is false. The relation of mathematical symbolism to ordinary language should be more fully developed for the student. A better understanding of both mathematics and language would result.

There is in the logical structural form of mathematics an aesthetic quality which justifies the assertion that mathematics is indeed an art. To ask anyone who really appreciates this characteristic why he studies mathematics would be tantamount to asking a man why he looks at a great painting or listens to a symphony.

There is also in mathematics a universality of a kind found in no other subject. I do not refer merely to the important fact that peoples of all nations share a common mathematics. (The same multiplication table is used on both sides of the Iron Curtain; the properties of geometrical figures are the same for all nationalities.) But more noteworthy is the extent to which mathematics pervades practically the whole of man's world. It plays the role of a servant in the marketplace. Geometrical forms and patterns are all around us, in art and architecture, in the hexagon of the honeycomb and the elliptical orbit of our planet. Questions of how many and how much are answerable precisely only in mathematical terms. The laws of nature are in many instances expressible only by mathematical equations. Number and form are indeed inextricably woven into the fabric of the universe. Try as he will, man cannot comprehend this universe without the aid of mathematics.

Much of this discussion of potential contributions of mathematics to a general education has been concerned with what might be called its intangible, perhaps even its impractical, aspects. This is not in any sense to disparage the practical utility of the subject. But in these days when there is a tendency in some quarters to exclude from our public school curriculum all subjects which do not have an immediate utilitarian purpose—a bread and butter, dollars and cents value—perhaps it is well to look at some of these so-called

impractical contributions. History is full of instances of studies and investigations pursued with no immediate use in mind which have in the long run been of incalculable value. The contribution of mathematics to a general education can no more be adequately measured by its immediate practical utility than can the benefits afforded by a study of Shakespeare's tragedies. In either case we are dealing with something whose depth and vitality render it worthy of all the thought and effort necessary to make actual—for as many students as possible—the unlimited educational values inherent in the subject.

Can We Reorganize the Mathematics Curriculum?

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TO SEEK an answer to the question "Can We Reorganize the Mathematics Curriculum?" it is desirable to know the context within which our thinking is to be done. What is general education? We shall use the words of the President's Commission on Higher Education in postulating that general education should emphasize "those phases of nonspecialized and nonvocational learning which should be the common experience of all educated men and women." We further postulate that it is the function of the total program of education to challenge, inspire, and encourage educable individuals to pursue those lines of personal endeavor that will provide that wisdom and understanding essential to the enjoyment of life as cultured human beings, responsible citizens, and competent performers in their respective areas of specialized interest. The guiding philosophy of the second postulate is essential as protection against the pitfalls of trivia as we seek to determine the significant implications of the first postulate.

The words "cultured," "responsible," and "competent" have relative connotations. By *culture* we usually mean "the intellectual content of civilization," which in turn implies "conversance with and taste in fine arts, humanities, and broad aspects of science." It is the function of education to provide opportunity for this intellectual attainment. If the schools should fail to pay attention to their health, religious, play, and even vocational responsibilities

to youth, there are other duly organized agencies which could and would extend their present services and thus protect youth against the unfortunate consequences of a deficient educational program. On the other hand, it is a principal responsibility of the elementary schools, secondary schools, and colleges of our nation to provide youth with the educational opportunity to exercise their individual aptitudes for and cultivate their respective interests in the intellectual content of civilization. Unless this responsibility is persistently emphasized in our thinking about the curriculum content of the educational program in our schools, there will be an irreparable loss to our society. Individual aptitudes and interests will vary widely, but psychology can help in detecting and making provision for these variations. Constant caution should be exercised, however, to protect against the tragedy of the failure to discover latent abilities which might die through lack of challenge or the inertia of mere inattention. It is somewhat of an unexplainable paradox that, in our modern world which, by leaps and bounds, is becoming more and more scientific in its pattern of life, we find an educational philosophy that tends to encourage a de-emphasis in attention to the "broad aspects of science"; and let us not forget that through the ages mathematics has been both "Queen and Servant of the Sciences." To speak of science one must think of mathematics.

When we speak of a *responsible* citizen we usually mean one who is capable of determining his own acts. The schools must supplement the home in the training of our youth to fit into and improve our democratic society. No program of education can be adequate if it fails to make provision for the fact that "the responsibilities of citizenship—are more complex [now] than ever before. Intelligent citizenship does not mean merely a simple faith in American Democracy. It calls for a thorough knowledge of political principles and institutions, of history, and of economics. It demands a clear understanding of the various sciences, for the intelligent citizen must help decide public policy on such complex matters as atomic energy. Above all, intelligent citizenship requires an ability to read, to understand, and to test the logic of arguments far more complicated than any that have hitherto been addressed to the public at large."[1]

It is true that the intellectual ability of an individual will affect the stature of his responsibility, as a citizen. Nevertheless, it is the

[1] Arthur E. Bestor, Jr. "Aimlessness in Education," *The Scientific Monthly*, 75, (1952), 109.

school's function to provide the educational content and guidance that will enable him to reach his full stature.

The implications of *competent* performance range all the way from that which is merely suitable to that which meets the demands of all requirements, no matter how stringent they may be. Either of these extremes calls for a measurement of performance in the light of accepted standards. It is true that standards for effort should be held distinct from standards for attainment, but evaluation of achievement in any area should never be at the expense of proficiency. Adults meet frustrations in their daily living and fail to be promoted from one level of performance to another in their chosen lines of endeavor. These frustrations and failures come as a result of inability or lackadaisical performance. The school cannot deal fairly with its pupils if it fosters a pattern of action that tends to encourage the incompetent and lazy to expect the reward of promotion without labor. Mathematics is an instructional area in which such policies have led to unpardonable sins. Pupils have been promoted from one grade level to another with no attention paid to the proficiency of performance in dealing with established skills and understandings. This has resulted in irreparable mental and emotional harm to many young boys and girls.

In the context of this concept of education the program in general education might be considered to have three main purposes: (1) To contribute to the individual's preparation for life needs—*not only those needs which he realizes but also those which he should be educated to realize;* (2) To provide for the integration of human knowledge and experience; and (3) To provide a nonspecialized type of preparation designed to have wide application, universal value, and great intellectual appeal. Among its most significant objectives would be found the intent to help the individual think carefully, communicate thought effectively, discriminate among values, improve and maintain his health, do his part as an active and intelligent citizen, choose a vocation, gain skill in adding to his previous knowledge, find self-expression in and develop an appreciation for things of beauty, and obtain sound emotional and social adjustments. Such a program does not become one in which standards are lowered and materials of instruction are "watered down" to make them easier. Rather it is one that recognizes the need for new emphases; the presence of differences in aptitudes and interests; the existence of fundamental concepts, basic skills, and intrinsic understandings of significance to all educable individuals;

and the possibility of treating such minimum essentials from the point of view of maximum worth to all those who participate. On the one hand, there will be the student who expects the program to terminate his educational venture *in parte* or *in toto*. For him, there should be the challenge, inspiration, and encouragement to strive to gain that wisdom and understanding which will enable him to accept the responsibilities of a cultured individual and a competent performer in a democratic society. On the other hand, there will be the student for whom the program should provide backgrounds of information which should serve him well as a clearer perspective for more significant specialization later in his educational endeavor. For him, there should be the challenge of future discovery, the inspiration of past achievement, the encouragement of individual attainment, and the confident satisfaction that he has acquired a broad, but solid, foundation in that wisdom and those understandings essential for subsequent intellectual adventure.

What place should mathematics have in such a program of general education? It would seem that the testimony of the years, both past and present, bears eloquent witness to the fact that it should have a place, and an important place. Mathematics has, through the ages, been a very important cog in the wheel of progress. The scientific and technological developments of the present seem to point to even greater significance in the future. There is a body of mathematical content that is of significance to every individual capable of intelligent participation in the educational program, whether it be at the level of the elementary school, secondary school, or college. The subject matter of such a program should be selected with great care and so organized and presented as to make significant provision for:

1. Functional competence in mathematics[2]
2. Communication of Thought
   a. Symbolic expression which emphasizes simplicity, conciseness, and effectiveness
   b. Use of graphs
3. Discrimination among values
   a. Interpretation of meanings
   b. Distinction between relevant and irrelevant data
   c. Intellectual independence
4. Aesthetic appreciation and expression

[2] One authoritative definition of functional competence in mathematics may be found in the "Second Report of the Commission on Post War Plans," *The Mathematics Teacher*, XXXVIII (May, 1945), 197-198.

5. Cultural advancement
    a. Basic significance to other subject areas
    b. Mathematical literacy
6. Effective thinking
    a. Sustained concentration
    b. Analytic thinking
    c. Postulational thinking
    d. Making generalizations
    e. Reasoning by analogies
    f. Evaluation of procedures and results
    g. Intellectual curiosity

Now to the question raised in the title: "Can We Reorganize the Mathematics Curriculum?" Sure we can, but let us beware that, in so doing, we do not find ourselves receiving, and deserving, the same tribute the learned judge gave to the retiring witness: "You are entitled to great credit, sir. You must have taken infinite pains with yourself. No man could naturally be so stupid." We live in an age in which possibly the only thing that is absolutely sure is change. As Langer has so aptly said:

> The tempo of life has become furious. And that inevitably means that the tempo of obsolescence has become so, likewise. We find it necessary to refashion our ideas and assume new responsibilities, we find it necessary to accustom ourselves to new price scales and modernized codes of living. To remain static in such times of stress means just one thing, namely to be left behind. We should be smug indeed if we were to think that mathematics and the teaching of mathematics could be excepted from these generalities. And if we grant that, it is certainly only the part of ordinary wisdom to take stock of ourselves and our practices.[3]

There is a need for *rethinking* the mathematics program in our schools. Maybe reorganization is needed, maybe it is not. Let us not be guilty of reorganizing just to effect a different arrangement. There has been too much of such futile and empty effort already. Rather, here is a serious and difficult problem which calls for conscientious, cooperative effort of an interested group composed of mathematicians, educationists, and psychologists. The group should be alert to the relative values of the old and the new in mathematics, the instructional and administrative problems of modern education, and the advances which have been made in clearer understanding of the techniques of learning and teaching. Such a group, and only such a group, can make a significant contribution to the reorganization of the mathematics program in our secondary schools.

[3] Rudolph E. Langer in his keynote address to the "Symposium on Teacher Education in Mathematics" held at the University of Wisconsin, August 26-30, 1952.

Scholarships for Teachers

A TOTAL of 102 fellowships and scholarships have been made available to members of the teaching profession for the summer of 1954 at the University of North Carolina. These awards are being set up to encourage further study on the part of leaders in the various phases of school work. All such scholarships will be awarded on a competitive basis.

The E. I. du Pont Company will provide twelve fellowships at $225.00 each plus all tuition and fees for the summer session. These are limited to teachers of science and mathematics.

Fifteen scholarships at $100.00 each for one six weeks' term will be awarded by the University Scholarship Committee.

Five scholarships valued at $125.00 each for one term will be awarded to outstanding persons in administration and supervision by the School of Education.

The Economic Education Workshop which operates for a three weeks' term will provide full expense for seventy persons.

Information about these scholarships may be secured by writing to Guy B. Phillips, Director of the Summer Session, University of North Carolina, Chapel Hill, N. C.

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Perhaps the most comprehensive work available to date. A book that should be in the personal library of every high school mathematics teacher. The extensive bibliographies are especially helpful.

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Weaver, Margaret. "Applying the Senses," *School Science and Mathematics,* 50: 655-661 (November 1950).

Some answers to the often asked question: "How can I make my science teaching practical?" Several projects given by way of illustrations.

Films on Science and Mathematics

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ATOMS AT WORK, 10 minutes, Sound, Black and White, British Information Services, 30 Rockefeller Plaza, New York 20, New York.

REPORT ON THE ATOM, 19 minutes, Sound, Black and White, McGraw-Hill Book Company, Text-Film Department, 330 West 42nd Street, New York, New York.

*WATER CYCLE, 10 minutes, Sound, Black and White, Encyclopaedia Britannica Films, Inc., Wilmette, Illinois.

THUNDER AND LIGHTNING, 11 minutes, Sound, Black and White, Young America Films, Inc., 18 East 41st Street, New York 17, New York.

LANGUAGE OF MATHEMATICS, 10 minutes, Sound, Black and White, Coronet Films, Inc., Coronet Building, Chicago, Illinois.

PARALLEL LINES, 10 minutes, Sound, Black and White, Johnson Hunt Productions, 6509 De Longpre Avenue, Hollywood 28, California.

*LIFE OF A PLANT, 11 minutes, Sound, Color, Encyclopaedia Britannica Films, Inc., Wilmette, Illinois.

*MONARCH BUTTERFLY, 11 minutes, Sound, Color, Encyclopaedia Britannica Films, Inc., Wilmette, Illinois. (High School Edition)

* Films may be secured from Bureau of Visual Education, University of North Carolina, Chapel Hill.